A COMPARISON OF JUDGMENTS FOR WEIGHTS LIFTED WITH THE HAND AND FOOT.

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INTRODUCTORY.

This series of experiments, begun in October, 1899, was undertaken for the purpose of determining the relative sensibility for "lifted-weights" through large and small muscles. At first attempts were made to use the large muscles of the leg and a flexor muscle of one of the fingers. That selection of muscles was soon abandoned because of the extreme difficulty, if not impossibility, of experimenting with the two muscles under anything like similar conditions. Finally it was decided to use the hand and foot as involving in a general way, large and small muscles. This then turns away, in part, from the original problem, but still involves the original to the extent that the muscles of the leg are larger than than those of the arm. Though suggestive, the experiments are in no wise conclusive as to the large and small muscle problem.[2]

After various attempts to eliminate the weight of the arm and leg, partly or wholly, this idea also was abandoned. It was taken up, however, in a second series of 4,500 tests not reported in this paper. The following is a report on 9,000 of the total 18,000 tests made. It is hoped that there is here furnished a reasonably safe answer to the question implied in the title of the paper, at least for one reagent.

The "standard weights" selected for this series of experiments are nine: 100, 400, 800, 1,200, 1,600, 2,000, 2,400, 2,800, and 3,200 grams respectively. Upon testing, the last weight proved to be about one-fourth of the reagent's maximum lift with the outstretched arm. The maximum lift for the leg proved to be about equal to that of the arm.

It was at first the intention to include larger standards up to

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[1] This paper was prepared as a thesis for the A. M. degree at Indiana University. The experiments were made under the direction of Dr. W. L. Bryan. Valuable suggestions have been given, also, by Dr. J. A. Bergström, Dr. Sanford and Dr. Hall.

[2] Bernhardt experimented incidentally with large and small muscles in a study of "Muscular Sense." Archiv. f. Psychiatrie, III, cited by Ferrier's Functions of the Brain, p. 391.

6,400 grams, that is, to one-half of the maximum lift.[1] But the larger weights could not be experimented with extensively, without excessive fatigue or even physical injury. The likeness of this scheme to Fechner's makes comparisons of results practical and suggestive.

Jaccoud,[2] Leyden,[3] Bernhardt,[4] Sunkel,[5] and Hitzig[6] have made experiments on weights lifted by the foot. In Jaccoud's tests twenty-four ataxic patients lifted weights ranging from 100 to 3,000 grams to determine whether such patients could recognize weight, and to some extent the differences of weight which might be recognized by them.

Leyden, Bernhardt and Hitzig experimented with normal reagents by the method of "Just-observable Differences."

As yet no very extensive experiments have been made with foot-lifting, and none to compare accuracy of judgment through hand and foot in the same normal reagents, so far as I know.

Apparatus.

The apparatus usually employed in lifted-weight experiments could not be used here. Fechner and Müller used essentially a rectangular base, from the corners of which brass rods extended upwards. These met in pairs at the ends, and were connected across by a wooden handle like that of a bucket bail. The weights were placed in the bottom of this rigid frame. While admirably suited for hand-lifts, this apparatus could not be used for the foot, but the lower portion of it could have been employed, doubtless, to some advantage. This is true especially of the method of arranging the weights and their respective instruments, *Zusatzgewichte*. In Fechner's apparatus this increment was placed in a small box which in turn was set into an opening in the center of the base. Thus every portion of his apparatus was firm and rigid.

Leyden in his foot-tests had a kind of pocket fastened to a band which hung over the instep. The weights were put into this pocket. Hitzig had the heel of a stocking sag downwards pocket-shaped and put the weights in this.[7] Bernhardt's reagent lay on his back and had a band around the instep of the foot. From the band a string passed under one pulley then upward over two others, and was attached to a small board on which the weights were placed.[8]

[1] Wreschner used 15 weights. The largest weighing 8,000 gr. Methodologische Beiträge. Leipzig, 1898.
[2] Paraplegies et l'ataxie du mouvement. Paris, 1864. p. 665.
[3] Ueber Muskelsinn und Ataxie. Virchow's Arch., 47, 321.
[4] Zur Lehre vom Muskelsinn. Arch. f. Psychia., III, 618.
[5] Inaugural Dissertation. Marburg, 1890.
[6] Neurol. Centralbl., VII, 249.
[7] Neurologisches Centralblatt. 7, 1888, 249.
[8] Arch. f. Psychiatrie, III, 628.

In attempts to devise apparatus equally suitable for both hand and foot, several forms were tried and rejected, which need not here be described. That used in these tests consisted of: (1) A board 6 x 8⅛ inches, the upper part of which was covered with a thick piece of cloth to avoid sounds and jars that might result from moving the increment; (2) Four strings attached to the four corners of the board, and meeting at a common point nine inches above the center of the board, where they were tied together and fastened to a single cord which continued upward about an inch. This single cord was inserted between the ends of the four strings and the collar above on the hand (or foot) so that if weight or increment should be placed, or slip, to one side, the variation would affect the direction of the suspended weight and the normal sensation as little as possible. To provide further against such effects the board rested on a thin cushion, so that the beginning and end of the lift might be affected as little as possible by any tipping of the board that might occur from a failure to center the weights properly; (3) A cylindrical band of heavy cloth with the diameter great enough to receive the fingers and palm of the hand (or the toes and a part of the foot). This band was sufficiently close-fitting to allow one to draw it to a given point and thus to keep it always in the same position and at a uniform distance from the joint. And since the arm is a lever this arrangement kept the distance from the weight to the fulcrum and power uniform. Over this band was fastened another of the same width but of greater length. It was sewed to the cylindrical band in a line along the upper side. The under side sagged downward about two inches, where it was gathered and tied to the single cord from below. This apparatus could be shifted easily from hand to foot, and was applied to about equal sense areas.

The apparatus, including the band, weighed 100 grams. The band alone weighed 26 grams. This series of experiments is at fault in that the weight of the band was on the hand constantly during each series of hand-tests. This was true, also, with the foot. Whatever absolute error in sensibility resulted from this source, its effect would be slight in comparing judgment for hand and foot, since both were subject to the same disturbing condition.

This error in apparatus should affect the absolute sensibility for the smaller weights more than for the larger ones, the band being proportionally a much larger part of the standard weight for small than for large weights. For 100 grams the weight of the band was one-fourth of the total standard; for 400, one-sixteenth; and for 3,200, only one one-hundred and twenty-

eighth. Leyden, Bernhardt and Hitzig appear not only to have left the apparatus on the foot while experimenting, but to have disregarded its weight, for they speak of distinguishing between 0 and 50, 83, 90 and 100 grams. In our tests the weight of the apparatus was always considered as a part of the weight to be lifted.

Standard gram-weights and books were used for standard weights. The increments were in the form of small muslin bags loaded with fine shot. In order to get results best suited for calculations by the tables in Dr. Sanford's Manual (p. 356), larger proportional increments were used for the smaller than for the larger weights, and for the foot than for the hand. These per cents were:

Standards,		100	400	800	1200	1600	2000	2400	2800	3200
Increments	Hand,	10	7	5	5	4	4	4	4	4
	Foot,	20	15	8	7	5	4	4	4	4

The particular selections of the above per cents were based on recorded experiments and on some 5,000 preliminary experiments not reported here. The larger per cents were used with the smaller weights in an attempt to get something near eighty-five per cent. of correct judgments, as giving best results with the current tables. In some respects it would have been better to use the same per cent. of increment throughout, as Fechner did. Such a plan gives greater significance to the doubtful cases. The varying per cents of increments allow no common basis for calculation of such cases.

METHODS OF EXPERIMENTING.

The experiments were made in sets of twenty of a kind divided about equally between heavy-first and light-first presentations, and were distributed as usual to avoid inequalities due to fatigue, training, the establishment of standard sensations, etc. Thus, a set of 20 tests with the hand, standard 100 grams, was followed by 20 tests with the foot, standard 100 grams; this, with hand, 400 and foot 400; and so on up the scale and back again. This was followed by foot, 100, hand, 100, etc., up and down the scale as before.

The individual tests were twenty seconds apart, and the two lifts constituting a test about two seconds apart. The latter time was not specifically measured, but was determined by the time required by the operator to place the increment on or take it off the apparatus, and to signal by tapping the hand or foot of the reagent. This time was very nearly uniform, and effort was made to keep it so. Variations from this source would be

almost equal for the foot and the hand. The average variation would render comparisons practically exact.[1]

Great pains were taken to keep the speed of the lifts uniform, and the same for both hand and foot. The speed has been shown to be a very important factor in the judgment of weights.[2]

An attendant noted the time for each test, moved the increment, signalled for the reagent by a gentle tapping of the hand or foot, determined whether a light or heavy presentation should be made, and recorded the results. The reagent had eyes closed and ears bandaged.

When tests of the hand were to be made the reagent sat on a dining-room chair by a table, with the arm outstretched and the hand projecting beyond the edge of the table. The board of the apparatus rested on the top of a piano stool, the supporting strings slightly loose. On receiving the signal the arm was kept straight and lifted. The stool was just high enough for the weight to clear it when the hand was about three inches below the level of the shoulder. The weight was then lifted about three inches and again lowered to the stool.

It is customary to gauge the height of a lift by a cord. The form of the apparatus made it quite impossible to do this. The writer is of the opinion that slight variations in height of lift are of but little consequence, since he appeared to base his judgments on changes of sensations at the beginning of the lift. After the lift the arm was again replaced on the table. As soon as the increment was changed and the signal given the lift was repeated. The result of judgment was announced by the reagent immediately after the second lift in each test. In the foot-tests similar precautions were observed, and the same plan of experimenting was followed.

In these experiments it will be noted that but two weights were used in testing a standard, 100, and the comparison weight, 110, when the smaller was presented first; or a standard, 110, and a comparison weight, 100, when the larger one was presented first. In the former case the increment was 10 per cent. of the standard; in the latter it was 9.09 per cent. This fact has been taken into account in working up the results and determining the curve.

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[1] Edgar James Swift (*Amer. Jour. of Psychol.*, V, 1-19) has shown that reaction time is materially lengthened by distracting the attention with the ticking of a metronome. Accordingly one would expect the unavoidable distraction from a metronome to induce a higher per cent. of errors in weight-judgments. But Dr. Margaret K. Smith has noted in "Rythmus und Arbeit" that all but one of her reagents rendered better judgments when weights were lifted with the tick of the metronome than without it.

[2] Müller and Schumann: Pflüger's Arch., XLV, 37-112.

Some experimenters[1] use a standard weight and then comparison weights of a given per cent. larger and smaller than the standard. Thus with 100 standard would be used 110 and 90; one, ten per cent. greater, the other, ten per cent. less than the standard. If it is desired to get a judgment on the basis of a ten per cent. increment it appears that the method employed in our experiments is more nearly correct than the foregoing method. Taking 90 and 110 for comparison weights, the greater is more than 20 per cent. greater than the lesser, and the lesser slightly less than 20 per cent. smaller than the greater. In case of such a method being used, judgment is rendered more on difference between comparison-weights than between standard and comparison-weights. One could render judgment heavier than standard or lighter than standard, after experimenting for a while, quite as well without the intervention of a standard as with it, on account of the great difference in the comparison weights. I find that this view has been expressed lately by Martin and Müller in their experiments on lifted-weights. They say: "We are by no means of the opinion that a comparison of weights never takes place. Those comparisons, however, which are the easiest to determine, are, strange to say, not comparisons between standard and its variables, but a comparison between a variable which has just been hefted and the variable of the immediately preceding experiment."[2]

In these experiments the reagent knew: (1) That there would be twenty tests in the set, divided as stated above; (2) That not more than four of a kind would come together; (3) Sometimes he knew that he had missed a given number in a previous set of the kind about to be undertaken; (4) That about such and such results might be expected from the hand-tests, *e. g.*, the light-first tests would show a higher degree of sensibility than the heavy-first tests would.

This makes the series, so far as absolute results are concerned, subject to some of the adverse criticisms directed against Fechner's work,[3] in addition to those already mentioned. Fechner, it will be remembered, was both operator and reagent in his experiments. Introspective observations, however, seem to indicate that the knowledge named above acted more as a spur to attention than to any other end.[4]

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[1] Wreschner: Metholodische Beiträge, Leipzig, 1898. Martin and Müller: Zur Analyse der Unterschiedsempfindlichkeit, Leipzig, 1899.

[2] *Amer. Jour. of Psychol.*, XI, 269.

[3] Fullerton and Cattell: "On the Perception of Small Differences," p. 116.

[4] For experiments with similar limitations, and a discussion of the same, see Psy. Rev. Sup. I, 31.

Practically two forms of answers were given; "second lighter, or heavier," when the distinction was clear; "second lighter, or heavier, D [doubtful]" when there was a very low degree of assurance. Introspective observations of various kinds were often noted in addition to the foregoing answers.

The results were worked up according to the method of Right and Wrong Cases, following Fullerton and Cattell's suggestions, and using the tables and methods of calculations offered by Dr. Sanford in his Manual.

In these tests an answer was always required from the reagent, however great his feeling of doubt. Investigators have not always dealt with the doubtful cases in this way. Fechner divided the doubtful cases equally between right and wrong judgments.[1] Wreschner threw them away;[2] Kraepelin, Jastrow, Fullerton and Cattell, and Higier required that the reagents should always answer no matter how great the feeling of doubt.

Table and Curve.

This curve and the accompanying table show the sensibility of the reagent's hand and foot and of Fechner's hand according to the method of Right and Wrong Cases. In determining sensibility from Fechner's experiments his right-hand tests were used. That the two series of experiments might be put on a par as far as possible, the three, five and ten hundred-gram tests of his were selected from sets where an increment of eight per cent. was used, while the others were taken from his tests with a four per cent. increment. Thus in this and in his series we have a large per cent. of increment with the lighter standards and a small per cent. with the heavier standards.

A comparison of Fechner's sensibility-curve with that of the reagent's hand in these tests will show them to be very similar in general form, though slightly different in detail and elevation. Individual differences, differences in apparatus, differences in methods of experimenting, and in the number of standards taken will, doubtless, account for the slight differences in results, was determined from the data on page 186, Vol. I, Psychophysik, 1889, with a full realization that he and the writer dealt quite differently with their doubtful cases. The comparison, therefore, is not fully justifiable, but is offered for whatever it is worth.

In Fechner's experiments six standards were used, while nine were used in these. This would tend to make his curve appear the more regular of the two.

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[1] El. d. Psychophysik, VIII, 72.

[2] *Amer. Jour. of Psychol.*, IX, 592. Gesellschaft fur psychologische Forschung. Heft II (III Sammlung).

Curves of Sensibility or Power of Discriminatiou. (9,000 tests.)

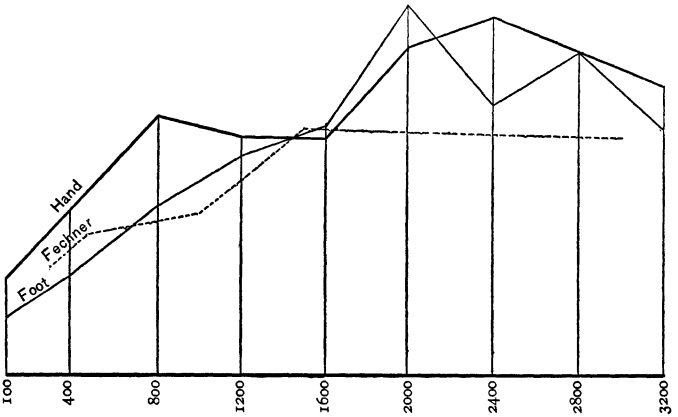

Table of Sensibility.

Standard W'ghts.	Hand.	Foot.	Standard Weights.	Fechner.
100	.093	.053		
400	.156	.094	300	.103
800	.242	.160	500	.132
1200	.228	.207	1000	.151
1600	.226	.231	1500	.232
2000	.328	.347	2000	.232
2400	.336	.251		
2800	.308	.308		
3200	.276	.235	3000	.229

Individual differences are often very great, however, and they alone could account for the variations in the curves.[1] For example, by the method of just observable differences Leyden's reagents showed a fineness of judgment for the foot double that of Bernhardt's. Müller and Schumann's subjects were less than half as sensitive as Fechner for certain weights.[2]

The grasp or hand-hold is probably an important factor. Cattell and Fullerton (Perception of small differences, page 118),

[1] Griffing: Psy. Rev. Sup., I, 42.
[2] Schäfer's Text-Book of Physiology, II, 1021.

with small wooden boxes to be grasped by the sensitive fingers, obtained an average sensibility of 161 when a standard weight of 109 grams was used. In these experiments, however, with a less active grasp and an appeal to a less sensitive dermal area[1] the sensibility was but .093, or about 9-16 as fine as theirs. Active effort undoubtedly enables one to judge more accurately than passive effort. Merkel found judgment based on active movement of the beam of a balance to be to passive pressure as 17 to 13.[2]

For the lighter standards this apparatus appealed to very small areas; but for the heavier standards, to large areas. The lightest weights merely produced slight movements in the band when the weight was lifted. The sensations from lifting the two weights appeared to differ only in that the band with the heavier weight rubbed the skin a little more than the lighter, usually along the side of the index finger. Fechner's apparatus, for the lighter standards, appealed to a larger area. Whether this difference of area affects the sensibility is a matter of dispute. Lemon[3] says it does, while Griffing[4] says it does not. In any event the curves show that where the dermal areas appeared to vary most, there the sensibilities vary most; yet the variation of sensibility may be due to other causes than differences of area.

There is probably a significant difference in the rigidity or firmness of the apparatus used. That used by Fechner, Müller and others consists essentially of a firm metallic or wooden frame, while that used here consisted largely of fabrics. With the solid frame the weight clears its base of support more suddenly than with our apparatus. With a rigid piece of apparatus a given speed of lift will make the changing sensations at the beginning of the lift pass more quickly than where the apparatus is less rigid. With our apparatus there is but little tendency for the weight to *fly up*. It is probable, also, that slight variations in the speed of the lift will affect judgment less with this apparatus. Upon the whole the other apparatus appears to be more exact, and should be used wherever possible.

Fechner's and these curves follow each other much more closely than any others[5] that the writer has seen.

As for the hand and foot curves in this chart, they closely resemble each other, even in detail, except at 2,400 grams. That variation is probably accidental.

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[1] For points, the sensibility of the tip of the finger is to that of the palm of the hand as to 1 and 5. Weber; cited by Bain: Senses and Intellect, 190.

[2] Phil. Stud., V, 287.

[3] The Skin considered as an Organ of Sense, p. 46.

[4] Psy. Rev., 1895, p. 128; also Supplement I Psy. Rev., p. 47.

[5] Hering, Müller and Schumann.

The curves show at first a rapid increase of sensibility to about the 800-gram standard, followed by a less marked increase up to 1,600. Then they rise rapidly to a maximum sensibility at 2,000 and 2,400, after which a slower decrease sets in. The cause of this change at from 800 to 1,200 grams is discussed under Hypothetical Considerations, further on in the paper.

The few tests made with much larger weights seem to indicate the continuation of this downward tendency in the curve, showing a further decrease in the sensibility. These tests with very heavy weights were not numerous enough to demonstrate anything, but at 6,400 grams, one-half of the reagent's maximum lift, they indicated a sensibility of not more than .125, which is less than that obtained with a standard of 800 grams. In the latter part of the paper, under "Hypothetical Considerations," is offered an explanation for this increase of sensibility, observed by all experimenters, as the scale of weights is ascended. In that section of the paper an attempt will be made to show that it is due to the influx of additional bases of judgment. The decrease of sensibility in the very large weights will be accounted for on the basis of an influx of distracting influences.

The difference in sensibility of the hand and foot, beyond 1,200 grams, is very small. The larger difference with the lighter standards may be due to finer dermal discrimination in the hand than in the foot, the basis of judgment for these standards being largely dermal.

Dr. Krohn has shown[1] that exposed surfaces locate better than portions usually covered with clothing, and Weber[2] found the sensibility for points on the dorsum of the foot to be to that of the palm of the hand as 5 to 18. Todd and Bowman[3] hold that the relative power of different parts to estimate weights corresponds very nearly with their relative capacities of touch, and Bloch[4] shows the weights, for just observable pressure for the palm of the hand and dorsum of the foot, to be as 1 to a weight ranging from 40 to 60.

These views put together make it appear altogether probable that there is a decided difference in the pressure and touch sensibility, for the dorsum of the foot and for the palm of the hand, and that this may account for the difference of sensibility as shown in the first part of the curves. But this difference is so small that it may be said, in general, that within the first quarter of the reagent's range of lifts, the sensibility of the foot for

[1] Psychol. Rev., 1894, p. 326.
[2] De pulsa, resorptione, auditu et tactu.
[3] Brit. Med. Jour., XIII, 430.
[4] Arch. de physiol., III.

lifted-weights is about equal to that of the hand, even though the foot had never before been used in lifting weights.

TABLE II.

Percentage of errors in the successive tests in all of the sets of twenty for both hand and foot.

No. of Test.	% of Wrong Judgments.	No. of Test.	% of Wrong Judgments.
1	30.23	11	22.66
2	18.22	12	24.88
3	21.33	13	22.66
4	19.77	14	18.88
5	23.77	15	23.99
6	24.00	16	19.77
7	23.50	17	23.12
8	21.11	18	23.55
9	20.88	19	26.21
10	26.21	20	24.33

This Table shows that on the average the first judgment in each series was poor, there being an average of 30.23 per cent. of errors for both hand and foot. While the average of the second tests shows only 18.22, or the smallest average per cent. of error in the whole set of twenty tests. This sudden improvement, after the first test, is the most characteristic thing shown in the Table. It is probably due to accommodation and setting up a standard sensation. It could hardly be due to increase of effort at attention over that rendered to the first test. It seemed to have taken the time up to the second test for the reagent to adjust himself to the series. Usually the attention was most intense at the beginning of the series, then a restful feeling of assurance, after three or four tests, was very common. If it be true that we underestimate weights when attention is intense,[1] that should not affect our judgments in comparing weights, as both standard and comparison-weight would appear equally reduced.

When concentration failed, as it did of necessity, occasionally, it never occurred with first, second, third, fourth or fifth tests. Introspectively, at least, the reagent would be of the opinion that attention was always most intense with the first test. Whenever attention was grossly at fault the reagent, without knowing the correctness or incorrectness of his answers, requested to be taken again over the last four or five tests, he not knowing exactly how much territory he was retracing. But every effort was made to keep attention uniform.

These tests it will be remembered were made twenty seconds apart. From last lift of one test to first of the next was about sixteen seconds. The standard sensation bridged over this time so distinctly that the reagent was able to render, in mind, after

[1] Psychol. Rev., I, 44.

the first lift of each, nearly one-half of the time, the same decision that he did render after making both lifts. The standard or absolute sensation, therefore, appears to have been an important factor in forming the judgments. In this view the charts and introspections here quite agree with Angell and Harwood, and with Martin and Müller, as stated by Angell in his review of the Martin and Müller article.[1]

Following the sudden improvement after the first test there is a slight general increase of error toward the close of the series, probably due to fatigue and diversions of attention. The principal factors entering into these variations are attention, fatigue and the establishment of standard sensations.

It is evident that the disturbances on the whole are not very great. For example, the first ten tests show 22.90 per cent. of errors, and the last ten 22.91 per cent.

But it is impossible in this study to isolate and measure these factors. Fatigue and inattention would tend to increase the wrong judgments, while the establishment of a standard sensation would tend to a decrease of the same.

The effect of training or practice was calculated and found to be very slight, the judgments through the foot showing a little more improvement than those through the hand. This extremely slight improvement, as shown in these experiments, is not so remarkable when we remember that about 5,000 tests had been made before this series was taken up.[2]

Summary of Results.

I. In answer to the main question of Comparison of Judgments: (a) The weights were discriminated a little better through the hand than through the foot; (b) The relative difference was greater for the small than for the large standards; (c) Both showed a lower degree of sensibility both above and below 2,000-2,400 grams, or one-third of the reagent's maximum lift; (d) The practice effects were small and about the same for both hand and foot; (e) The discrimination of the heavy-first presentations differed from the light-first presentations in the foot-tests less than in the hand-tests. (This fact has not been discussed in this paper. For the hand the variation was slightly above the average. For the foot it was probably less than the average hand-variations.) (f) The sensation seems to be partly a touch and partly a muscular sensation as observed by Fullerton and Cattell; (g) The fineness of discrimination is not materially disturbed by the fatigue resulting from

[1] *Amer. Jour. of Psychol.*, 1899-1900, p. 260.

[2] On effect of training see Wreschner, Metholodische Beitrage, p. 183. Leipzig, 1898, pp. 238.

a short series of tests; (h) Standard sensations play an important rôle in a series of like judgments; (i) The second test of the series are judged better than any others.

II. Some Introspective Observations. (a) The judgments in tests on 100-gram weights seemed to be based quite exclusively on mere touch-sensations; (b) The judgment seemed to be based more on the changes in stimuli that occurred at the beginning of the lift, than on any constant sensations after the weight once cleared its base of support. The best results were obtained by directing the attention to the first sensations. Swinging the weight up and down did not seem to improve the discrimination much, if any; (c) The accuracy of judgment varied greatly, sometimes even with no apparent cause; (d) Very quick and very slow lifts were hard to judge; (e) In lifting the large weights the judgment seemed to be based principally on "muscular sensations;"[1] (f) Very small increments make judging very fatiguing by their great demands on attention; (g) One can distinguish quite noticeably when lifting very large weights, that he is beset with a focal[2] sensation, and with numerous marginal sensations, some having only a distracting influence upon the attention, such as noises, heat, the pains from uncomfortable positions, and muscular pains; and others, that must be regarded as auxiliary sensations to the focal sensation. They, with the focal sensation, figuratively, in a heap, constitute the real basis of discrimination. Among these marginal auxiliary sensations the following were pronounced: (1) Touch sensations around the grasp; (2) Pressure sensations; (3) Changes in the pressure of the back against the back of the chair; (4) Increased pressure on the seat of the chair; (5) Feet pressing more firmly on the floor; (6) Other hand putting forth effort wherever it may be placed; (7) Interference with breathing; (8) Interference with circulation; (9) Intercostal and abdominal muscular sensation.

Some of these may pass over and become sources of distraction rather than auxiliary sensations.

Hypothetical Considerations.

The following hypotheses are based partly on the data determining the curve given in the first part of the paper, and partly on the introspections noted as the experiments were being made.

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[1] Sensations based on specific sense-organs in muscles, tendons, joints, and all of the accessory organs of movement. Schäfer's Text-Book of Physiology, Vol. II, 1006. Macmillan, New York, 1900.

[2] By *focal sensation*, it is intended to designate one toward which the mind is primarily directed.

Basis of Judgment.

In stating the basis of judgment for lifted-weights it is convenient to divide the field of sensations into two classes, focal and marginal. When weights are being lifted the focal sensation is usually, though by no means always, the sensation for which the stimuli change most vividly.

Besides this focal sensation there are many marginal sensations in consciousness down to a feather-edge in "subconsciousness." Some of these tend to draw attention away from the focus, and thus to induce poorer judgment: others seem to go along with the focal, to be auxiliary sensations, and by their presence to induce a finer discrimination.

These marginal auxiliary sensations are often very marked where hardly anticipated. When conducting some tests where the reagent lay on his side on the floor, several judgments with the larger standards were rendered with the attention fixed upon the tendency to slide along the floor in the opposite direction from the pull that was being made. Surprisingly enough the feeling of assurance and the correctness of the decisions were quite as good as when the attention was directed to the muscular sensations of the arm. But the fact of these marginal sensations does not prove that any of them are auxiliary in forming the judgment.[1] Jastrow and Bruce bandaged the arm tightly so as to empty most of the blood, and then rubbed the skin with ice. This greatly reduced the sensibility of the skin, but did not affect the judgment for lifted-weights. (Letter to the writer.) Here subtracting some of the marginal sensations did not affect the judgment.

"According to the law of perception[2] of weight by the sense of cutaneous pressure alone, it requires the addition of one-third of the original weight, whatever it may be, to produce a distinctly perceptible difference; but in Bernhardt's experiments on the foot it was found that the addition of from three to five Loth (1½ to 2½ oz.) to an original weight of from a pound to a pound and a half could be distinctly perceived, which is less than one-half of the increment perceptible by cutaneous pressure alone.

In regard to the discrimination of weight by the finger, the sensibility was found to be much finer. Three drachms could be distinctly differentiated from nothing, and to heavy weights (say 1 pound) the addition of five drachms was dis-

[1] Pierce and Jastrow (Memoirs of the Nat. Acad. of Sci., III, 1884,) showed that even the mere guesses on small differences fall according to law predominantly on the side of right judgments. Thus it appears that the subconscious states are factors that must be taken into account in judgments.

[2] Ferrier: Functions of the Brain, p. 391.

tinctly perceived, *i. e.*, a difference of about 1/16, a power of discrimination which corresponds pretty nearly with that of the muscular sense, which is capable of detecting an addition of 1/17 of the original weight. These results, therefore, indicate that the discrimination was much finer than could be effected by the sense of pressure alone, and that, therefore, it depended on muscular discrimination."

It seems that the presence of marginal sensations on which, singly, a fair judgment could be based, and all of which are induced by stimuli from a single source, within normal limits, should increase the accuracy of judgment. The presence of such a sensation may decrease the nicety of judgment of the focal sensation. But still it would have to be shown whether the decrease in the focal sensation is not more than compensated by such a marginal sensation as described above.

In whatever position one may be when he makes a lift the auxiliary marginal sensations are present. They vary greatly as larger standards are used. With their cumulative influx, up to certain limits, they probably increase the acuteness of discrimination. When very great, however, they may become sources of distraction.

With the very small weights the marginal consciousness is very limited in extent. Until a given degree of motion or tendency toward it is reached at any sensitive part of the body, no sensations result. Some organs and processes are disturbed earlier than others as the scale of weights is ascended. Hence, this gradual increase in the extent and intensity of the marginal consciousness. So it happens that, as the scale of standards is ascended, new marginal sensations keep coming in and rising higher and higher in consciousness. Some of the marginal sensations may become so strong as to take over the focus to themselves. And this is just what appears to happen, the muscular sensations which are at first marginal, later, become focal, and with the very heavy weights, sources of distraction, while the dermal sensations become marginal. Biedermann and Löwit found that the dermal sensibility to pressure decreases very rapidly above 450 grams. At 450 the least observable difference was 1/69, and at 500 grams it was 1/20 of the standard weight.[1]

This influx of marginal sensations, and transposition of focal sensations, from the tables and from the introspective observations, seems to have been most marked at from 800 to 1,200 grams. At 2,800 and 3,200 breathing and circulation were quite perceptibly disturbed. With the very large weights the

[1] Hering: Sitzungsber d. Wiener, Akad., LXXII, 342. Ladd's Physiological Psychology, 368.

sensations of strain about the shoulder, chest and abdomen may become focal.[1] With the latter weights also came certain marked distractions, as, muscular-pain from the heavy lift, and an unavoidable trembling of the arm.

It is probably entirely impossible to isolate completely these various sources and bases of judgment so as to determine the comparative worth of each for various standards, and within what limits Weber's, Fechner's or any other law holds. It may be that some law holds for each of the several bases after it becomes a factor in the discrimination, probably Weber's, but that no law has been or, possibly, can be formulated to apply to the sum of them.

Views of experiments are not wanting on the subject. G. E. Müller has called attention to the probability of a gradual influx of additional sensations.

With the larger weights come first muscular sensations with the upper and fore arm; and with very large weights, from the muscles of the chest and shoulder. One must ask, then, to what extent Weber's law is valid. The lifted arm may be a part of the lifted weight. To determine the validity of the law one must know whether any, or part, or all of the arm goes in with the given weight to make up the weight on which we really base our judgments. Moreover, the antagonizing force of the opposite and adjacent muscles cannot be known.[2]

Hering, long ago in a letter to Fechner, pointed out the probability of a complex of sensations as the basis of judgment.

"At the same time," says Bastian,[3] "a number of impressions emanate from the back of the hand, which, so far from aiding him in his judgment, would be a source of mental distraction. Then I would say, also, that, in estimating such weights as Weber employed, the person would almost certainly have experienced sensations emanating from the muscles themselves; and there is really no reason for believing that these sensations, derivable from a muscle which is contracting somewhat strongly, do not reveal themselves to us by means of ordinary sensory nerves in the muscles. I believe that they are due to the common sensibility of the muscle testifying to its own organic conditions, and that these sensations may well be part components of the impressions by which we are enabled to judge of differences of weight. And if this be the case, then it was to be expected, as I think, that there should have been a much greater power of discriminating differences of weight when the common sensibility of muscle was allowed to act in conjunction with the tactile impressions, than when these latter

[1] Ferrier's Function of the Brain, p. 392.
[2] G. E. Müller: Grundlegung der Psychophysik, p. 202.
[3] Brit. Med. Jour., XIII, 1869, 439.

were appreciated alone and apart from all distracting influences." He holds the muscular sense, however, to be only a fraction as delicate as the pressure sense.

We note that our view does not agree with Ferrier's[1] which seems to set aside all joint, tendon and purely muscular sensations in the arm. He says, "I am of the opinion that the discrimination of heavy weights calls into play the general sense of effort, which, as we have seen, is the more properly ascribed to the region of the respiratory muscles, and that the discrimination in this case is affected by the amount of bodily strain and fixation of the muscles of the chest necessary to support a heavy weight; and that it is not a question of the muscular sense of the limb at all, unless general strain is absolutely eliminated by continuous and easy respiration during the trial. When this is eliminated it will be found that the sense of local resistance is the only element in the discrimination of weight."

Weber considered that the reason for finer judgment in lifting, over that of mere pressure, was due to the muscular sense coming in as a further basis of judgment.[2]

The above views, except Ferrier's, seem to tally with the writer's introspections which may be restated briefly thus: Judgment of weights is based on focal and auxiliary marginal sensations, which change greatly as the scale of weights is ascended. The focal sensation changes from dermal to muscular, but may be voluntarily placed elsewhere; the marginal group constantly increases; and some sensations pass from auxiliary to distracting sensations.

In lifting a weight there is probably a normal rate of change in sensations at which the total amount of change can be judged most accurately, varying, to be sure, with different reagents. Change may be either too rapid or too slow for accurate judgment. J. S. Lemon[3] states that great pressure can be made without producing consciousness of the fact, providing that it be applied very gradually. Fontana, showed that a slight pressure on a nerve might be increased gradually until the nerve was crushed, without producing motion in the corresponding muscle. Heinzmann[4] and Fratscher[5] boiled reflex frogs without sensation enough to produce motion by applying the heat very gradually.

Very rapid changes make strong sensations, but sensations lacking nicety for distinction. Fullerton and Cattell,[6] on the

[1] Functions of the Brain, 392.
[2] Living Age, XIII, 12.
[3] Skin Considered as an Organ of Sensation: Whiting, and Whittaker, Gardner, Mass., 1899.
[4] Archiv. f. die gessammte Physiol., VI, 1872, 222.
[5] Jenaische Zeitschrift, I, 1875, 130.
[6] Perception of Small Differences, p. 131.

basis of a few experiments, held that the rate of lift does not increase the probable error. In changes of pressure it is claimed that the more rapid the changes the greater the accompanying distractions.[1]

It is precisely this change of sensations, occurring from the beginning of the lift until the weight clears its support, that we compare and judge, rather than the totality of sensation after the weight is up. The reagent will judge best when the speed and other conditions are most favorable for his taking these changes into full consciousness. If the normal speed is maintained, the height of the lift is of but little consequence, providing the reagent holds firmly to the changes which occurred at the beginning of the lift. But when the reagent defers judgment, he is liable to question his impressions and do little more than guess. Even when judgment is not at once declared and dismissed, one is apt to conclude that his impressions may have been in error. Moreover, the pressure, and probably other sensations, decrease rapidly after the application of the weight.[2] From our standpoint the basis of judgment appears to be the memory of a former change of sensation as compared with a present changing sensation.

The notion that the judgment is based partly on the sense of effort we pass by. The sense-of-effort view has been pretty generally abandoned.[3] If sense of effort exists at all it may be said to assume the relation of marginal sensation. Neither does it appear, with this apparatus, which picks up the weight more gradually than does Fechner's and Müller's apparatus, that the speed of the lift is so important as Müller and Schumann[4] found it to be. The speed, here, appears to be but one of the marginal sensations.

Interferences of Sensations.

Judgments of sensations are disturbed by two kinds of sensation-interference: (1) distraction, and (2) fusion. Distraction through sensations occurs whenever sensations arise which tend to draw the focus of attention to themselves, and thus away from any sensation or group of sensations which one is trying to judge. Interferences of this kind have been referred to at various places in this paper, and, for our present purposes, do not need to be discussed further here. This kind of interference has been pretty generally recognized, and has been studied rather extensively. Distractions arising

[1] Hall and Motora: *Amer. Jour. of Psychol.*, I, 87.
[2] Psychol. Rev., Sup. I, p. 30.
[3] Schäfer's Text-Book of Physiology, II, p. 1002.
[4] Pflüger's Archiv., XLV, 36-112.

from the fusion of sensations seem to have been studied but very little. I believe it would be entirely practicable to study them experimentally. The following is offered as an hypothetical application of this variety of interference involved in lifted-weights.

Sensations very unlike and with their stimuli remotely located are readily distinguished as different. But as the stimuli approach each other in kind and location, it becomes more difficult to discriminate them. Again, the more usual and neutral as to pain and pleasure a sensation is, the more readily and completely can it be disregarded for others to which we wish to give especial attention.

Now, it was quite clear to those who tried the apparatus used in the foregoing experiments, that the conscious basis of judgment was tactile for the 100-gram standard. The marginal auxiliary sensations, if present, were wholly subconscious. This tactile sensation is altogether unlike the sensations arising from lifting the arm, and the latter, if not continued too long, are usual, normal, neutral. The mind should, therefore, readily differentiate these two sensations and neglect the usual neutral arm-weight sensations. It would seem, then, that the weight of the arm does not in the least interfere with the judgment of small weights, with this apparatus, any more than the breathing, touch of the clothing, or any other neutral sensation interferes with thinking the binomial formula in algebra. In our opinion, as the standard increases in weight, the marginal sensations loom up in consciousness, more and more, and gradually the muscular sensations gain the ascendancy. Then some of the sensations arising from lifting the weight become identical in kind and location with those arising from lifting the arm and the mind cannot, naturally enough, distinguish the two. What was a four per cent. increment on the weight is now less than four per cent. on the total amount of standard-weight and some arm-weight measured in terms of sensation. This reduction of the per cent. of increment in the focal stimulus tends to decrease accuracy of judgment for a given standard and a given per cent. of increment of it. The weight of the arm thus gradually insinuates itself into the standard.

It is not probable that we judge one weight as just a little more than another; that would contradict all of our experience with Weber's law. If that were true the same difference would serve for distinguishing any two weights, no matter how large or small. The increments must be regarded as per cents of the standards, and since the weight of the arm seems to change this per cent. as the scale of weights is ascended, the weight of the arm may be expected to interfere with the judgment.

But if the weight of the arm does not get confused with the standard-weight, or rather if the sensations do not fuse for the small weights and this does happen with the larger ones, then why is the discrimination not poorer for the larger than for the smaller weights? If our hypothesis shears close enough to the truth, then it would follow that the marginal subconscious sensations more than compensate the loss through the interference of arm-weight.

This, it seems, may explain, in part at least, how the weight of the arm interferes in the discrimination of lifted-weights. The hypothesis is offered as such only, and not as something proven, simply a possible explanation for a part of the problem.

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